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HYPERSPECTRAL OBSERVATION FOR OPTICAL PROPERTIES OF COASTAL BENTHIC COMMUNITIES IN THE SMALL ISLAND

(Observasi Sifat Optik pada Organisme Bentik Perairan Dangkal di Pulau-Pulau Kecil menggunakan Teknology Hyperspektral)

By/oleh :
Nurjannah Nurdin[1], Teruhisa Komatsu[2], Hiroya Yamano[3], Gulam Arafat[1], Chair Rani[1] and Awaludinnoer[1]
[1] Marine Science Department, Hasanuddin University, Makassar, 95245. Indonesia.
[2] Atmosphere and Ocean Research Institute (AORI), The University of Tokyo, Japan.
[3] National Institute for Environmental Studies, Tsukuba-City, Japan.
Email : nurjannah@aori.u-tokyo.ac.jp, nurj_din@yahoo.com, komatsu@aori.u-tokyo.ac.jphyamano@nies.go.jp

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ABSTRACT

Collecting the spectral library of different bottom types is an important step in mapping shallow water bottom types with of remote sensing. Five small islands in the Spermonde archipelago, South Sulawesi, Indonesia, were selected to measure the reflectance spectral of benthic communities. The objectives of this study are to determine optical properties of the live corals, dead corals covered with algae, coral rubble, broken shell, sand, seagrass and to collect a spectral library of bottom types present around small islands in the Spermonde archipelago. Several benthic communities appear to be highly correlated with one another when the entire spectrum considered, which may lead to classification errors. Porites meyeri, dead corals and coral rubble (>3 months ago) share a high degree of similarity in reflectance. The other coastal benthic communities are readily distinguishable.

***Keywords** : Spectral, Coral Rubble, Living Corals, Dead Corals, Broken Shell*

ABSTRAK

Pengumpulan pustaka spektral pada berbagai jenis dasar perairan merupakan langkah yang penting dalam memetakan karakteristik dasar perairan dangkal dengan menggunakan teknologi penginderaan jauh. Pada penelitian ini, pengukuran reflektansi spektral pada komunitas bentik perairan dangkal dilakukan pada lima pulau-pulau kecil yang terdapat di Kepulauan Spermonde, Sulawesi Selatan, Indonesia. Tujuan dari penelitian ini adalah selain menentukan karakteristik optik pada karang hidup, karang mati yang ditumbuhi alga, pecahan karang, pecahan cangkang, pasir dan lamun juga untuk membangun pustaka spektral berbagai jenis obyek dasar perairan dangkal yang terdapat di sekitar pulau-pulau kecil Kepulauan Spermonde. Beberapa komunitas dengan jenis komunitas bentik lainnya menunjukkan korelasi yang kuat yang akan menghasilkan kesalahan klasifikasi jika menggunakan julat spektrum yang lebar seperti antara karang Porites meyeri, karang mati yang ditumbuhi alga dan pecahan karang yang telah berumur lebih dari 3 bulan menunjukkan tingkat kesamaaan reflektansi spektral yang tinggi. Sedangkan pada obyek dasar perairan dangkal lainnya, nilai pantulan spektralnya dapat dipisahkan.

***Kata kuci** : Spektral, Pecahan Karang, Karang Hidup, Karang Mati, Pecahan Cangkang.*

INTRODUCTION

Knowledge on the spectral separability of benthic communities is useful for designing and optimizing coral reef remote-sensing applications (Atkinson et al., 2001). The spectral library presented may provide the opportunity for reliable classification of submerged coral reef ecosystems thus reducing the cost of the monitoring project. It may also aid scientists and managers using remote sensing in selection of optimal band location and bandwidth characteristics. Spectral libraries of coastal benthic communities could substantially improve mapping accuracy of coral reefs maps when applied in remote sensing image classification.

Optical signatures of corals and other coral reef benthic types collected in different parts of the world (Clark *et al*., 1997, 2000; Holden and LeDrew, 1999, 2000, 2001; Kutser *et al*., 2000, 2003; Schalles *et al*., 2000; Dekker *et a*l., 2001; Hochberg *et al*., 2003, 2004; Karpouzli *et al.*, 2004; Kutser *et al*., 2006; Nurdin and Rani, 2009; Rundquist *et al*., 2009) show that the shapes of reflectance spectra of live corals, dead corals, sand, seagrasses, green, brown and red algae are consistent in different locations of the world. This suggests that a classification of remote sensing imagery based on the optical signatures of different benthic types should be applicable in different locations of the world even if no field data is available.

The benthic communities of the Spermonde archipelago, Indonesia are characterized by a high biodiversity. Veron (1993) reported that there are over 400 different species of hard coral alone. Thus, a large and comprehensive spectral library of substrate types is needed in order to resolve the spectral variability found in the Spermonde archipelago, Indonesia. Spec-tral measurements using a radiometer were collected for the first time in Manado, Indonesia in 1997 by Holden and LeDrew. They measured spectral reflectance of typical coral reef features including healthy branching coral, healthy massive coral, bleached coral, algae-covered surfaces, dead coral debris and sand substrates. Our research is the second time in Indonesia. Using *in situ* reflectance data we extent the work of Holden and LeDrew (1998) to examine whether living corals can be spectrally distinguished from corals at various stages of mortality and algae colonization.

The objective

The objective of this study is to determine optical properties of the live corals *Acropora formosa, Seriotopora stelata, Acropora macrostomata, Acropora sarmentosa, Porites columnaris, Montipora sp, Porites meyeri*), dead corals covered with algae (dead Porites and dead Acropora), coral rubber covered with algae (>3 months ago and <3 months ago), broken shell, sand, seagrass (*Enhalus sp, Cymodocea sp, Thallasia sp, Halophilla sp, Syringodium sp*), macro algae (*Sargassum sp, Turbinaria sp, Padina australis*) and to collect a spectral library of benthic communities present in Spermonde archi-pelago, Indonesia. Whereas, this research will contribute to supply baseline information on optical characters of coastal benthic communities in tropical area that can be used as a basic knowledge in interpretating satellite images so that they facilitate in identifying existence and differentiating some benthic communities types, especially using hyperspectral.

METHODOLOGY

Study Sites

Spermonde archipelago consist of over one hundred small islands that have valuable marine resources and extremely rich ecosystems. Five small islands on the Spermonde archipelago, South Sulawesi, Indonesia, were selected to measure the reflectance spectral of benthic communities (**Fig.1**). Samatellu Lompo, Samatellu Borong, Samatellu Pedda, and Gusung are in Samatellu Islands area (119°19'32,65"-119°21'57,85"BT,4°2'1,01" - 4°43'10,52"LS) where many fishermen are practicing blast fishing. Gusung and Samatellu Pedda island are still uninhabited. The last, Barrang Lompo island (119° 19', 14,6" – 119° 19', 55,85" BT and 5° 2' 29,62" – 5° 3' 18,7" LS) is densely populated. Spectral measurements were conducted in Barrang Lompo Island and in Samatellu islands on January-Pebruary 2010 under generally clear skies using LOT-2 Spectra Corp. The data collection measured between 9:00 a.m. and 15.00 p.m. Central Standard Time, when the sun is high in the sky.

Benthic Communities Spectra Collection

We select coral reef area having high heterogeneous by using *manta towing* tech-nique and determination of station points. The manta tow technique is useful for selecting sites that are representative a large areas of reef (Pemetta, 1993). Dark measurements taken in each experiment were used to subtract additional operational noise.

A calibrated white reference standard was used following each sample measure-ment, placed at the exact location and height of the sample. Spot measurement of individual substrate types were made from about 7 cm above the substrate, resulting in a field of view of about 1.5 cm. Each measurement took about half a minute, capturing over one hundred spectra. Benthic communities were identified by biologists, generally at a species level.

The total number of substrates for which reflectance spectra were collected was 352. A total of 90 representative samples of living coral and 26 of dead coral covered with algae, 106 of coral rubble, 58 of macro algae, 15 of broken shell, 15 of sand, and 42 of seagrass were selected randomly.

We studied the optical properties of the *in situ* measured coastal benthic commu-nities and devided the substrates into the following classes: live corals (*Acro-pora formosa, Seriotopora stelata, Acropora macrostomata, Acropora sarmentosa, Porites columnaris, Porites meyeri*), dead corals covered with algae (dead *Porites* and dead *Acropora*), coral rubble covered with algae (>3 months ago and <3 months ago), broken shell, sand, seagrass (*Enhalus sp, Cymodocea sp,*

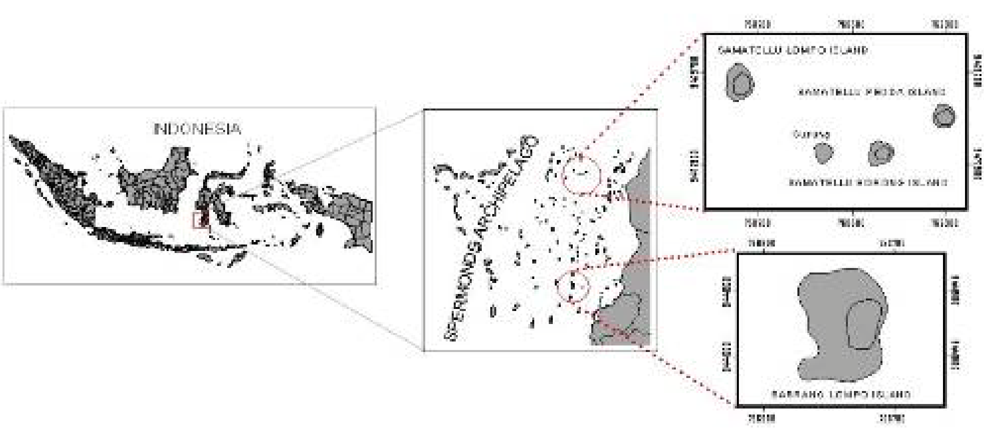

Figure 1. Location of the Samatellu Lompo, Samatellu Borong, Samatellu Pedda, Gusung and Barrang Lompo island study sites in Spermonde archipelago, South Sulawesi, Indonesia.

Thallasia sp, Halophilla sp, Syringodium sp), and macro algae (*Sargassum sp,* and *Padina australis*).

The reflectance spectra were taken over each sample between 2 and 5 meters, and each spectrum was the result of averaging of individual scans compiled over approxi-mately 30 seconds. The spectral range of the LOT-2 Spectra Corp instrument is 300 - 1100nm. Spectra are sampled with 3 nm intervals. In some cases reflectance spectra of seagrass and algae were measured on board the boat immediately after collecting the substrates. To achieve a pure signal, leaves were piled on matt black background in multiple layers (O'Neill *et al.,* 1990).

Data Analysis

Correlation analysis and Cluster analy-sis were applied to analysis the data. Cluster analysis was used to determine spectral similarity in and among coral species based on spectral responses at observed wavelengths. Similarity scale used was euclidean distance. Distance scale determined spectral similarity and dissimilarity in which object with shorter distance would be more similar each other compared to object with longer distance.

RESULTS

Benthic communities Spectra

The benthic communities in Spermonde archipelago were as follows: live corals, dead corals covered with algae, coral rubble covered with algae, broken shell, sand, seagrass and macro algae. In the present study the coral rubble were divided into recent one (less than 3 month) and long time (considerably greater than 3 month) based on visual classification of attached algae cover. Dead coral was greater than 3 months. Recent coral rubble which was white, were covered with small quantify turf algae and coralline white is visible clearly. Old coral rubble are mainly covered with dence turf algae that growing rapidly and significantly darker than recent coral rubble and therefore more easily separable.

Reflectance spectra showed shape and magnitude similar between broken shell and sand (**Figure 2A**). These groups appeared similar in spectral magnitude to dead corals covered with algae. Differen-ces were apparent in the relative magnitude of reflectance of green and NIR wave-lengths by each benthic communities. It was somewhat more difficult to distinguish reflectance differences between dead corals when the corals were covered with algae.

Reflectance of dead *Porites*, dead *Acropora*, and coral rubble (>3 months) were almost identical to those *Porites meyeri* and *Acropora macrostomata*. Dead *Porites* appeared similar in spectral magnitude and shape to dead *Acropora* (**Figure 2B**). They have a peak reflectance at 605 nm and reflectance minimum at 674 nm. Coral rubble had a minimum at 674 nm. This is most similar characteristics between live corals and dead coral. It suggests that all of these surfaces house algae (**Figure 2C**). *Sargassum sp, Turbinaria sp,* and *Padina australis* were similar in spectral magnitude and shape (**Figure 2D**). The peak reflectance at 556 nm with the minimum at 667 nm. Reflectance values of coral rubble and macroalgae showed similar pattern of peak and minimum. Trough all of the measured parts of the live corals showed distinctive spectral features (**Figure 2E**), such as a peak reflectance at 579 nm, and drop at 674 nm, and a steep rise around 700 nm. Furthermore, with few exception, *Steriotopora stellata* spectra displayed highest reflectance (9%). The peak at 556 nm and minimum at 674 nm were common seagrass group (**Figure 2F**).

Spectral Correlation

Correlation analysis used average spectra of each nineteen categories of the benthic communities. When the entire average spectrum was used the correlations between categories became high, suggesting a high degree of overall similarity. It is indicated that spectral reflec-tance within benthic communities were spectrally similar. Several benthic commu-nities in this study were highly correlated with one another when the entire spectrum considered, which may lead to classification errors. Sand and seagrass are not highly correlated, indicating that they should be accuratelydiscriminated (**Table 1**). The Pearson correlation analysis revealed there was a strong correlation within live corals. However, low correlation was detected between sand, broken shell and the others communities benthic except coral rubble. Correlation between dead *Acropora*, dead *Porites*, algae and live corals were high. And there was a strong correlation wthin seagrass.

Table 1. Correlation coefisient for nineteen categories of benthic communities

	Acropora formosa	*Seriotopora stelata*	*Porites meyeri*	*Porites columnalis*	*Acropora macrostomata*	*Acropora sarmentosa*	Coral Rubble (<3 months)	Coral Rubble (>3 months)	Sand	Broken shell	*Sargassum sp*	*Padina australis*	*Enhalus sp*	*Cymodocea sp*	*Thallasia sp*	*Syringodium sp*	*Halophila sp*	Dead Acropora	Dead Porites
Acropora formosa	1																		
Seriotopora stelata	0.96	1																	
Porites meyeri	0.89	0.90	1																
Porites columnalis	0.96	0.95	0.98	1															
Acropora macrostomata	0.97	0.93	0.96	0.99	1														
Acropora sarmentosa	0.97	0.94	0.95	0.99	0.99	1													
Coral Rubble(<3 months)	0.86	0.84	0.95	0.93	0.91	0.89	1												
Coral Rubble (>3 months)	0.77	0.76	0.96	0.90	0.88	0.86	0.96	1											
Sand	0.30	0.32	0.59	0.46	0.41	0.38	0.72	0.75	1										
Broken shell	0.66	0.66	0.83	0.77	0.73	0.71	0.95	0.91	0.86	1									
Sargassum sp	0.86	0.82	0.98	0.95	0.96	0.93	0.94	0.97	0.60	0.82	1								
Padina australis	0.97	0.93	0.97	0.99	0.99	0.99	0.94	0.90	0.47	0.79	0.96	1							
Enhalus sp	0.94	0.96	0.81	0.88	0.87	0.88	0.81	0.66	0.27	0.63	0.72	0.88	1						
Cymodocea sp	0.97	0.98	0.83	0.92	0.91	0.92	0.80	0.68	0.23	0.61	0.76	0.91	0.99	1					
Thalasia sp	0.97	0.96	0.82	0.90	0.90	0.91	0.81	0.67	0.25	0.63	0.74	0.90	0.99	0.99	1				
Syringodium sp	0.92	0.93	0.73	0.83	0.82	0.84	0.74	0.57	0.19	0.57	0.64	0.83	0.99	0.98	0.99	1			
Halophila sp	0.89	0.89	0.73	0.80	0.79	0.80	0.77	0.59	0.28	0.63	0.64	0.81	0.98	0.94	0.96	0.97	1		
Dead Acropora	0.85	0.85	0.98	0.94	0.92	0.90	0.99	0.98	0.71	0.92	0.97	0.95	0.78	0.79	0.78	0.70	0.72	1	
Dead Porites	0.81	0.80	0.95	0.91	0.89	0.87	0.99	0.98	0.74	0.95	0.95	0.92	0.74	0.74	0.75	0.67	0.70	0.99	1

Spectral clustering

Clustering of reflectance ranging between 400 to 750 nm showed a similarity distance. Display of group division at overall wavelengths was presented in dendrogram graph as shown at **Figure 3**. There were seven main groups at similarity distance of 66.6%, i.e., *Acropora formosa* having spectral similirity with *Seriotopora stelata*, categorized in to one group. *Enhalus sp* and *Thallasia sp* were one group. *Porites meyeri* having spectral similirity with old coral rubble, dead *Acropora* and dead *Porites*, categorized in one group. *Acropora macrostomata* and *Acropora sarmentosa* categorized in one group.

Cymodocea sp, Halophila sp and *Syringodium sp* were one group. Recently coral rubble, broken shell and sand were in one group. *Porites columnaris* having spectral similarity with *Padina australis, Turbinaria sp, and Sargassum sp* were categorized in to one group.

At similirity distance of 84.08%, it was show fifteen groups, i.e., *Porites meyeri* having spectral similirity with old coral rubble, categorized one group. *Acropora macrostomata* and *Acropora sarmentosa* categorized in one group. Broken shell and sand were one group, dead *Acropora* and dead *Porites* were in to one group. *Porites columnaris* having spectral similarity with *Padina australis,* were categorized in one group. However, *Acropora formosa, Seriotopora stelata, Porites columnaris,* recently coral rubble, *Turbinaria sp, Sargassum sp, Cymodocea sp, Halophila sp* and *Syringodium* formed a group. Similarity level formed was high within dead corals groups. Broken shell, and sand have a similirity spectral. Porites meyeri and old coral rubble had a high similirity level.

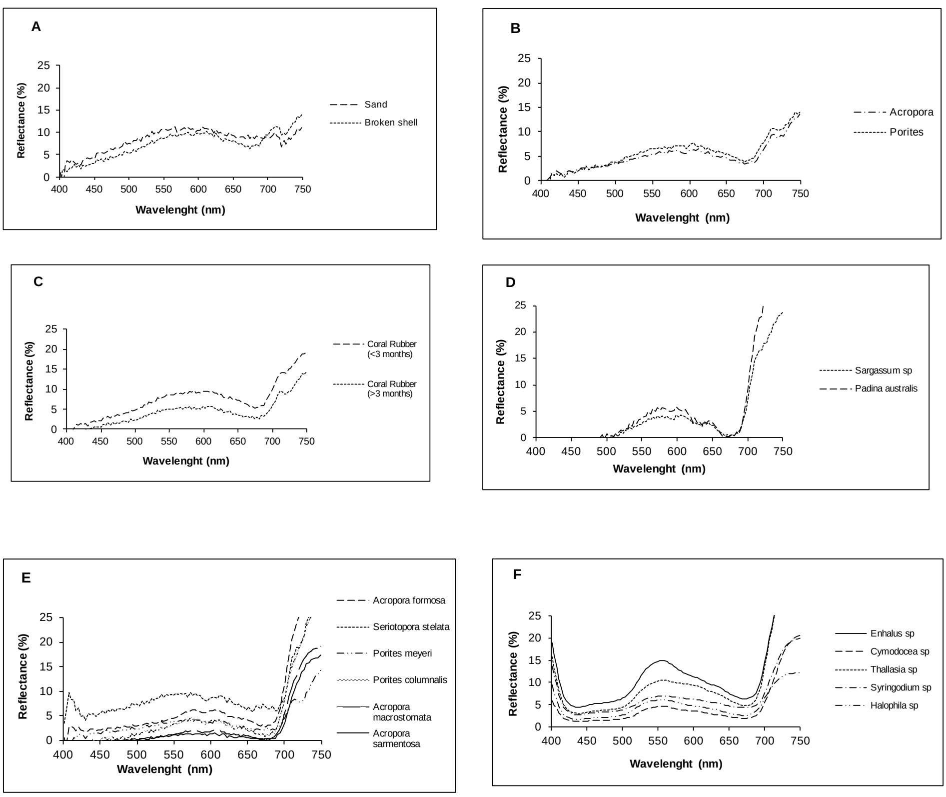

Figure .2. Averaged reflectance spectra of each category or object. (A) Broken shell and sand, (B) Dead coral covered with algae, (C) Coral rubble covered with algae, (D) macro algae, (E) live corals, and (F) Seagrass are averages of each group. Dead coral covered with algae are represented by a reflectance spectrum of *Porites* and *Acropora*, macro algae by *Sargassum sp*, *Turbinaria sp* and *Padina australis*, live corals by *Acropora formosa, Seriotopora stelata, Acropora macrostomata, Acropora sarmentosa, Porites columnaris, Porites meyeri* and seagrass by *Enhalus sp, Cymodocea sp, Thallasia sp, Halophilla sp,*and *Syringodium* spectrum.

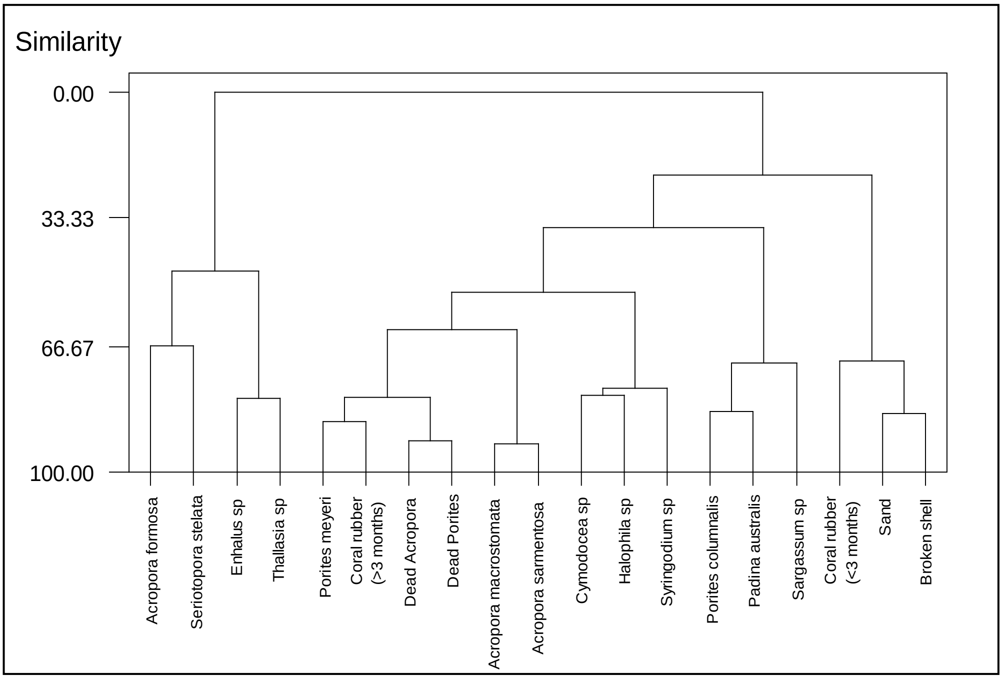

Figure 3. Dendogram of twenty categories divided into six live corals (*Acropora formosa*, *Seriotopora stelata*, *Acropora macrostomata*, *Acropora sarmentosa*, *Porites columnaris*, and *Porites meyeri)* and 2 dead coral covered with algae (*Acropora*, and *Porites*), 2 coral rubble covered with algae (<3 months and >3 months), 2 macroalgae (*Sargassum sp*, and *Padina australis*), 5 seagrass (*Enhalus sp*, *Cymodocea sp*, *Thallasia sp*, *Syringodium sp*, and *Halophila sp*,) broken shell and sand

DISCUSSION

The spectral reflectance characteristics of live corals were shown to have great variance as well. Coral colonies of the same species may have slightly different coloration (Veron, 1993). We examined this phenomenon using six coral species: *Acropora formosa, Seriotopora stelata, Acropora macrostomata, Acropora sarmen-tosa, Porites columnaris,* and *Porites meyeri.* Each of these species exhibited variability in reflectance spectra both in magnitude and shape. Chlorophyll in the zooxanthellae is an efficient absorber of light at the wavelength transmitted by seawater, but its fluorescence emission at 685 nm and longer wavelenghts is strongly absorbed by seawater (Mazel and Fuchs, 2003). Our results are in general agreement with other studies, which measured light signals returned from corals. When light interacts with objects such as coastal benthic communities, it is either absorbed or reflected. Absorbed photons may be immediately re-emitted at longer wave-length, contributing to surface reflectance (Mazel, 1996). Here we show a conside-rable in the reflectance spectra of 352 samples of 6 hard coral species, 2 dead corals types, 2 coral rubble types, 3 macro algae species and 4 seagrass species, collected within five islands that were located in Spermonde archipelago.

Coral rubble is covered with epiphytic algae after bleaching by blast fishing activities. As time goes on, epiphytic algae become thicker. Reflectance of coral rubble is changed with period after bleaching. Epiphytic algae become visible size by three months after bleaching. Therefore coral rubble showed the similar shape but have a different of spectral magnitude and peak position between two groups of coral rubble. These differences could be used as precise indicators and predictors for identifying coral rubble conditions reflecting the chlorophyll concentration. It contributed significantly to the increase in value of reflectance. Broken shell and sand had a similar color. They have the highest reflectance value. Differences in size between them had little effect on spectral reflectance than pigment composition. Sand and broken shell exhibit the same relative spectral shape, because the dominant absorbing component in each is the mineral calcium carbonate.

Reflectance spectra of live coral, and coral rubble covered with algae showed that there were more spectral variations in the shape than dead coral covered with algae. However, any significant differences in spectral reflectance were found within dead coral covered with algae category. Their reflectances were generally lower in the shorter wavelength region (400-500 nm) and is most cases, there were not distinctive features between them. The spectral reflectance of live coral was only slightly different than the spectral reflectance of dead coral. The difference can be found where dead corals spectral show a peak reflectance at 605 nm and peak reflectance of live corals at 579 nm. This spectral similarity could potentially lead to classification errors. On the hand, live corals, dead corals, coral rubble, broken shell and sand had a similar of minimum in reflectance at 674 nm. When chlorophyll of algae absorbs light, this means that micro and macro algae colonize rapidly on the surface of a dead corals, coral rubble, sand and broken shell. when algae containing chlorophyll colonized the debris surface, it will not reveal the absorbance characteristics in this wavelength. The computed component spectra of algae and of bleached coral are similar. This phenolmenon could be explained by the potential that algae had already colonized the bleached coral surfaces as a result of the increased vulnerability of the coral (Holden and LeDrew, 1999).

The seagrass leaves displayed a distinctive drop in reflectance 667 nm because of chlorophyll absorption and was peak reflectance around 556 nm. A peak between 550–555 nm appears to be a common feature of seagrass reflectance over wide geographical regions, and the rise after 700 nm and the lack of a steep single slope from 550 to 680 nm. The spectral discrimination between aquatic plant species must concentrate on their pigment related spectral features within the visible wavelengths, where light penetrates the water column and can be reflected back to the sensor (Fyfe, 2003).

The spectral reflectance of the each benthic communities showed an significant result that a narrow absorption wavelength exist in the spectral at 579 nm, and very strong spectral reflectance from 697 nm towards the longer wavelength. A broad reflectance maximum of around 579 nm is caused by a low absorption of algae. A low reflectance, from 400 nm to 500 nm, is due to both chlorophyll-a and dissolved organic matter absorption (Gitelson, A., 1992).

The results of cluster analysis are encouraging with respect to the separability of benthic communities reflectances. Similarity level among some groups formed was high or on the other word spectral reflectance variability among them was low. *Porites meyeri* was in the same group with dead coral covered with algae and old coral rubble had a similiar reflectance. This indicated that *Porites meyeri* couldn't be easily separated from dead corals and old coral rubble. Living coral, dead corals covered with alga, and coral rubble covered with algae as photosynthetic organisms displayed a reflectance minimum at approximately 674 nm, a feature related to the presence of chlorophyll. The living coral and coral rubble reflectance spectra showed the most variation in shape and magnitude in comparison with th other groups (**Figure 2A**).

Our results were similar to Holden and LeDrew, 1999 that there is a certain degree confusion between healthy coral, bleached coral and algae. Since the macro algae contain photosynthetic pigments, the confusion with healthy coral containing zoo-xanthellae is understandable. If compared to several other studies, even though with different coral species showed supporting results. The overall results of this cluster analysis suggest good separation based on measured reflectance.

Using *in situ* measurements of light return from different benthic communities, we have documented that a differences in the magnitude and shapes of spectral curves from different substrates and a strong absorption at 674 nm. Our measu-rement at shallow water depth should primarily represent reflectance behaviour and differences in the magnitude and shape of reflectance spectra from different benthic communities are largely the result of variations in symbiosis pigment concentra-tions and proportions. According to Kirk (2003), that solar radiation has very wide spectrum, however, those absorbed for photosynthesis are only spectrum that less or same with visible light spectrum i.e. 400 nm to 700 nm (also known as PAR = photosynthetically active radiation). Longer wavelength than 600 nm will be absorbed by chlorophyll-*a,* whereas the shorter wavelengths will be absorbed by accessory pigments. Thus it is not surprising that reflectance of benthic communities show variability at these study.

In fact, reflectance of coastal benthic communities is readily distinguishable. However, *Porites meyeri,* dead corals and coral rubble (>3 months) share a high degree of similarity in reflectance. At the same time, it is possible that live coral groups themselves are distinguishable among them. The spectral library presented may provide the opportunity for reliable classification of coastal ecosystems thus reducing the cost of the monitoring project. It may also aid scientists and managers in selection of optimal band location and bandwidth characteristics. Benthic commu-nities can potentially be mapped from remotely acquired spectral imagery, provided that they have distinctive reflectance signatures

REFERENCES

Atkinson MJ, Lucey PG, Taylor GJ, Porter J, Dollar S, Andréfouët S. 2001. *CRESPO: Coral Reef Ecosystem Spectro-Photometric Observatory.* Concept study report to the University Earth System Science Program. National Aeronautics and Space Administration. University of Hawaii.

Clark CD, Mumby PJ, Chisholm JRM, Jaubert J, Andre´foue¨t S. 2000. Spectral discrimination of coral mortality states following a severe bleaching event. *Int J Remote Sens* 21:2321–2327

Dekker, A. G., Brando, V. E., Anstee, J. M., Pinnel, N., Kutser, T., Hoogenboom, E. J., Peters, S.,Pasterkamp, R., Vos, R., Olbert, C. & Malthus, T. J. M. 2001. Imaging spectrometry of water. In *Imaging* Spectrometry*: Basic Principles and Prospective Applications* (van der Meer, F. D.& de Jong, S. M., eds), pp. 307.359. Kluwer Academic Publishers, Dordrecht.

Gitelson, A. 1992. The peak near 700 nm on radiance spectra of algae and water: relationships of its magnitude and position with chlorophyll concentration. *International Journal of Remote Sensing*, 13, 3367± 3373.

Hochberg EJ, Atkinson MJ. 2000. Spectral discrimination of coral reef benthic communities. *Coral Reefs* 19:164–171.

Hochberg EJ, Atkinson MJ, Andre´foue¨ t S. 2003. Spectral reflectance of coral reef bottom-types worldwide and implications for coral reef remote sensing. *Remote Sens Environ* 85:159–173

Hochberg E.J, Atkinson M.J, Apprill A, Andréfouët S. 2004. Spectra reflectance of coral. *Coral Reefs* 23, 84–95.

Holden, H. and LeDrew E. 1998. Spectral Identification of Coral Bleaching based on Principal Components, Cluster and Spectral Derivative Analysis. *Remote Sensing of Environment*, 217-224

Holden H, and LeDrew E. 1998. Spectral discrimination of healthy and non-healthy corals based on cluster analysis, principal components analysis, and derivative spectroscopy. *Remote Sensing of Environment* 65:217–224.

Holden H, and LeDrew E. 1999. Hyper-spectral identification of coral reef features. *Int J Remote Sens* 20:2545–2563.

Holden, H. and LeDrew E. 2000. Accuracy Assessment of Hyperspectral Classification of Coral Reef Features, *Geocarto International*, 5-11.

Holden, H. and LeDrew E. 2001, Hyper-spectral discrimination of healthy versus stressed corals using in situ reflectance, *Journal of Coastal Research*, 17(4), 850-858.

Kutser T., Vahtmae, E., and Metsamaa, L. 2006. Spectral library of benthic macroalgae and other Estonian coastal water bottom types. *Proceedings of Estonian Academy of Sciences*. Biology Ecology. 55:329-340.

Karpouzli A.E, Malthus T.J, Place C. 2004. Hyperspectral discrimination of coral reef benthic communities in the western Caribbean. *Coral Reefs*. 23, 141-151.

Kirk, J. T. O. 1994. *Light and photosyn-thesis in aquatic ecosystems*. Cambrid-ge Univ. Press. New York. USA.

Kutser T, Dekker AG, Skirving W. 2003. Modeling spectral discrimination of Great Barrier Reef benthic communities by remote sensing instruments. *Limnol Oceanogr* 48:497–510

Kutser, T. & Jupp, D. L. B. 2006. On the possibility of mapping living corals to the species level based on their optical signatures. *Estuarine Coastal Shelf Sci*., 69, 607.614.

Mazel CH. 1995. Spectral measurements of fluorescence emission in Caribbean cnidarians. *Mar Ecol Prog Ser* 120: 185-191

Mazel CH. 1996. Coral fluorescence characteristics: excitationemission spec-tra, fluorescence efficiencies, and contri-bution to apparent reflectance. SPIE Volume 2963-*Ocean Opt XIII* 1:240–245

Mazel CH and Fuchs E (2003) Contribution of fluorescence to the spectral signature and perceived color of corals. *Limnol Oceanogr* 48:390–401

Mishra D, Narumalani S, Rundquist D, Lawson M. 2007. Enhancing the Detection and Classification of Coral Reef and Associated Benthic Habitats: A Hyperspectral Remote Sensing

Approach. *Journal of Geophysical Research*, 112, C08014.

Nurdin N, and Rani C. 2009. Optical Properties of Soft Coral Species in Tropical Marine Waters. *Proceeding International Conference on Natural & Environment Science*. Banda Aceh. Indonesia, 77-83.

O'Neill, A.L., S. Hardy, and S.I. Fraser. and K.R. McCloy. 1990. Leaf morphology and the spectral reflectance of some Australian plant species. p. 1096–1103. In *Proc. of the 5th Australasian Remote Sensing Conf*. Perth. Australia.

Rundquist D, Gitelson A, Lawson M, Keydan G, Leavitt B, Perk R, Jennifer Keck, Mishra DR, Narumalani S. 2009. Proximal Sensing of Coral Features: Spectral Characterization of Siderastrea sidereal. GIScience & Remote Sensing, 46, No. 2, p. 139–160.

Schalles JF, Rundquist DC, Gitelson AA and Keck J. 2000. Close range, hyperspectral reflectance measurements of healthy Indo-Pacific and Caribbean Corals. In: *Proc of the Sixth Intern Conf, Remote Sensing for Marine and Coastal Environments*. Veridian ERIM Intern, Ann Arbor, MI, USA, I: 431- 440.

Stambler N. and Sharhar N. 2007. Variation in spectral reflectance of the hermatypic corals *Stylophora pistillata* and *Pocillo-pora damicornis*. *Journal of Experimental Marine Biology and Ecology* 351: 143–149.

Veron, J.E.N. 1993. *Corals of Australia and the Indo-Pacific*. Univ. Hawaii Press. Hawaii.

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